Determination of Micromechanical Deformation in Nanocrystalline Materials

When a material is subjected to an external load, the resultant mechanical deformation is a complex three-dimensional response. Further the resultant response can vary widely depending on the mechanism at the level of interatomic bonds. One possible response mechanism is an elastic flexure of these bonds. The deformation due to this mode is reversible and is traditionally classified as the elastic response. However, for many materials there are other reversible modes of deformation; most important of these is due to a stress driven phase transition. Another class of deformation modes is when the resultant deformation is permanent and does not recover on release of the external load. These modes of deformation are traditionally classified under the heading of plasticity. An important mode of plasticity in a material arises from dislocation dynamics. But again, many advanced engineering materials undergo plasticity via many other modes, such as detwinning and grain re-orientation. The mechanical response to a given increment in the external load for even very similar materials is dramatically different depending on the mode of deformation. Because of the 3D nature of the mechanical response and a myriad of different deformation modalities available, even small local inhomogeneity and material anisotropy make most critical mechanical responses, such as yielding, fracture and crack propagation, very local phenomena. Therefore, for a deeper understanding of the mechanical response of advanced engineering materials to external load, it is not only necessary to be able to accurately determine the full 3D deformation response locally, but also have the ability to discriminate among different micromechanical modalities that the response invokes.

Traditional strain measurement methods cannot measure the full 3D response or directly discriminate among the different micromechanical modes of deformation. Whereas diffraction based strain measurement techniques have the capability of not only accurately determining the full 3D elastic response but also easily distinguishing among the various micromechanical modes. Further, with very high brightness x-ray beams located at synchrotron facilities and much improved focusing optics, these determinations can be done at a very local spatial scale.

Implementation of diffraction methods using white beam Laue geometry to determine the 3D deviatoric elastic response for a single crystal, or in cases when the crystallites are bigger than the x-ray spot size, has been well established and extensively applied to many problems in mechanics. The x-ray spot sizes at these beamlines are in the range of a few hundred nanometers to a few microns, and it appears that significant reduction in the spot size beyond this range, while still providing sufficient flux for diffraction work, appears to be very difficult. But a large class of advanced engineering materials are nanocrystalline, either by design or often due to mechanical deformation. The nanocrystalline crystallite size makes white beam microdiffraction techniques inappropriate for these materials.

Use of monochromatic powder diffraction was proposed several decades ago and has been used over the years, as the $\sin^2\psi$ technique, to obtain a fraction of the full 3D elastic response. But because of prohibitively long times required the technique has never become widely used in mechanics. In this presentation we will demonstrate a modification of the monochromatic approach using a large area detector to obtain the full (deviatoric and the hydrostatic) 3D mechanical response from nanocrystalline materials as quickly as the white beam microdiffraction method. We will further apply this implementation of the monochromatic beam strain measurement techniques to obtain a deeper understanding of the portioning of forces in nanocrystalline materials and specifically, its effects on superelasticity in NiTi, an advanced material that is revolutionizing the field of biomedical devices.